Stabilization Wedges

A Concept and Game

This presentation is based on the “Stabilization Wedges” concept first presented in

"Stabilization Wedges: Solving the Climate Problem for the next 50 Years with Current Technologies,” S. Pacala and R. Socolow, Science, August 13, 2004.

Roberta Hotinski, Ph.D.

CMI
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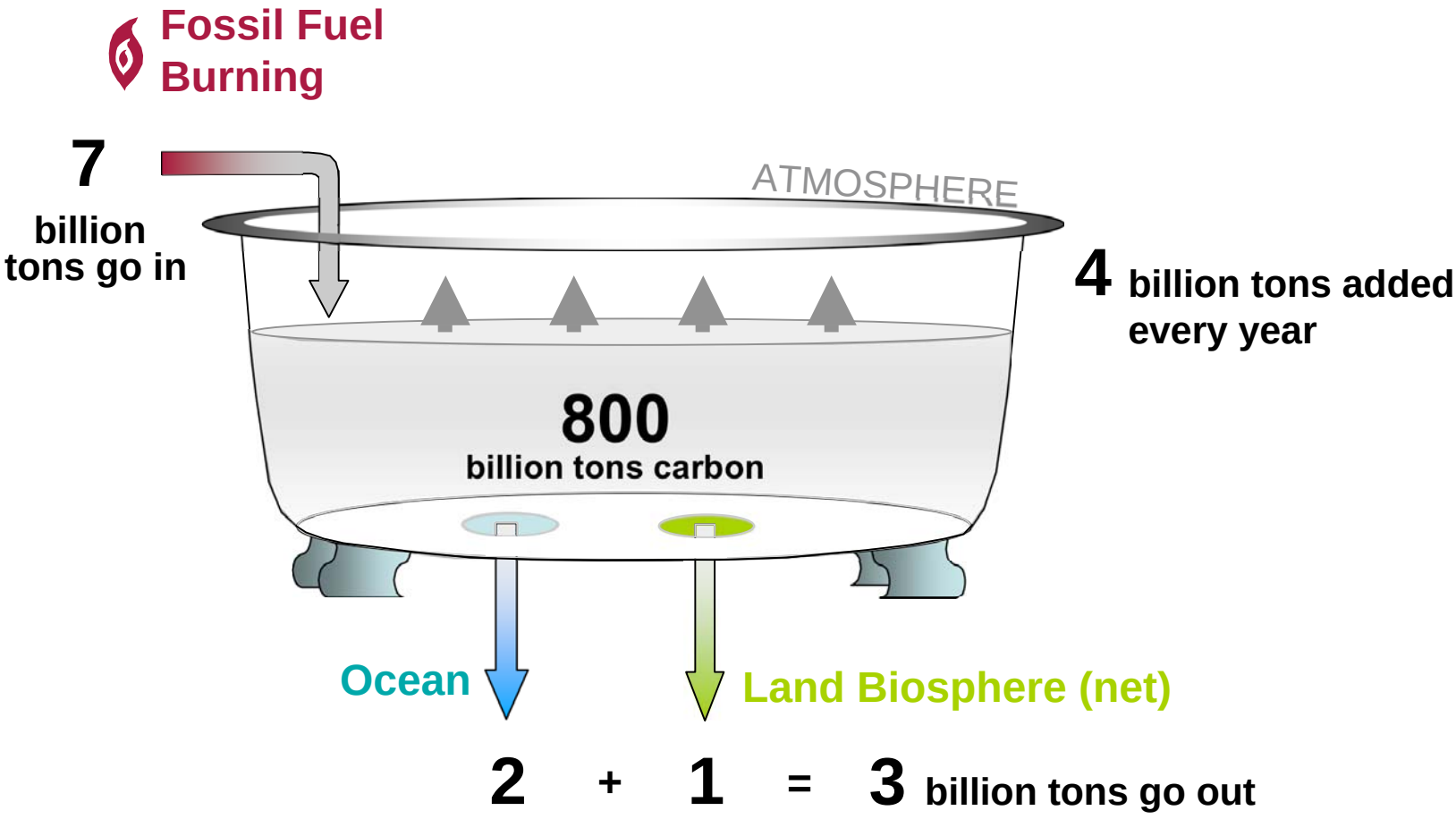
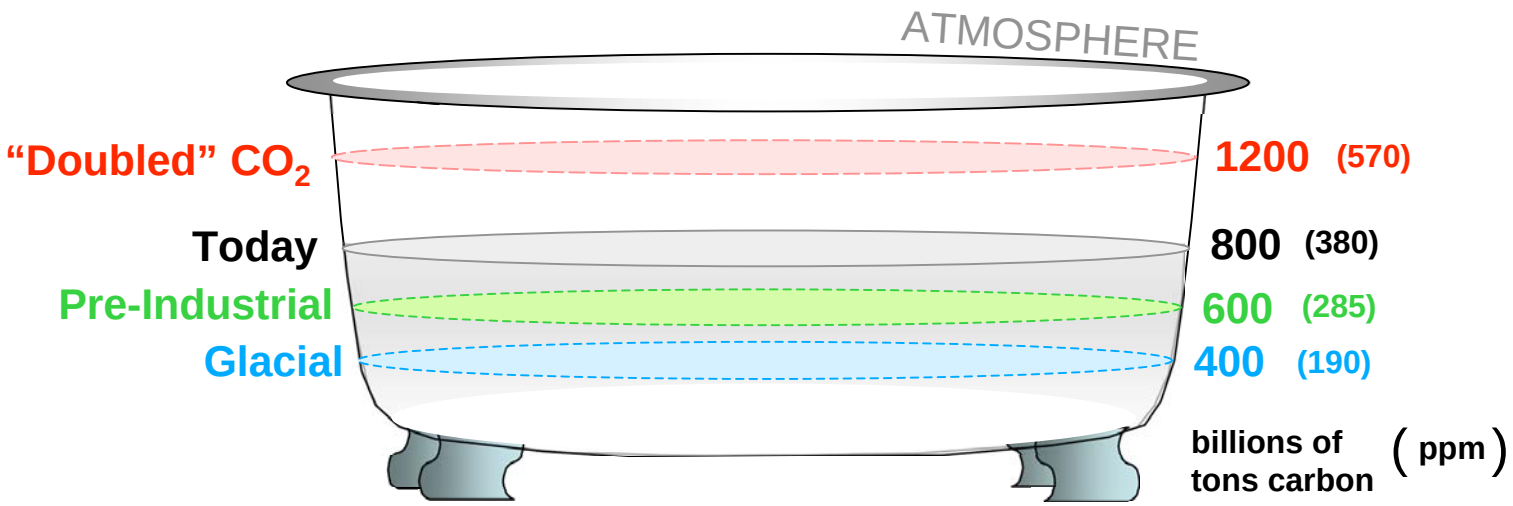
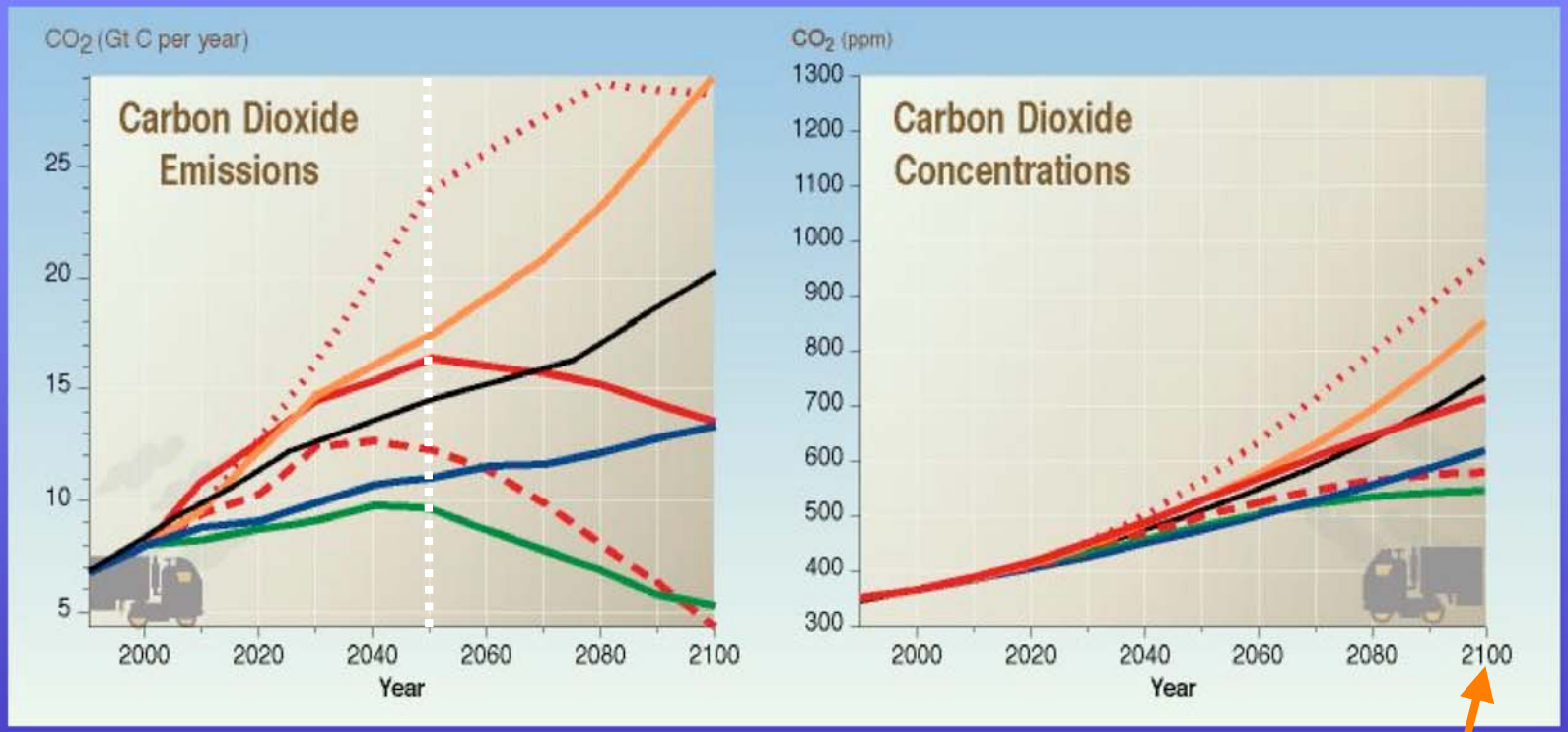
The Atmosphere as a Bathtub



Past, Present, and Potential Future Carbon Levels in the Atmosphere



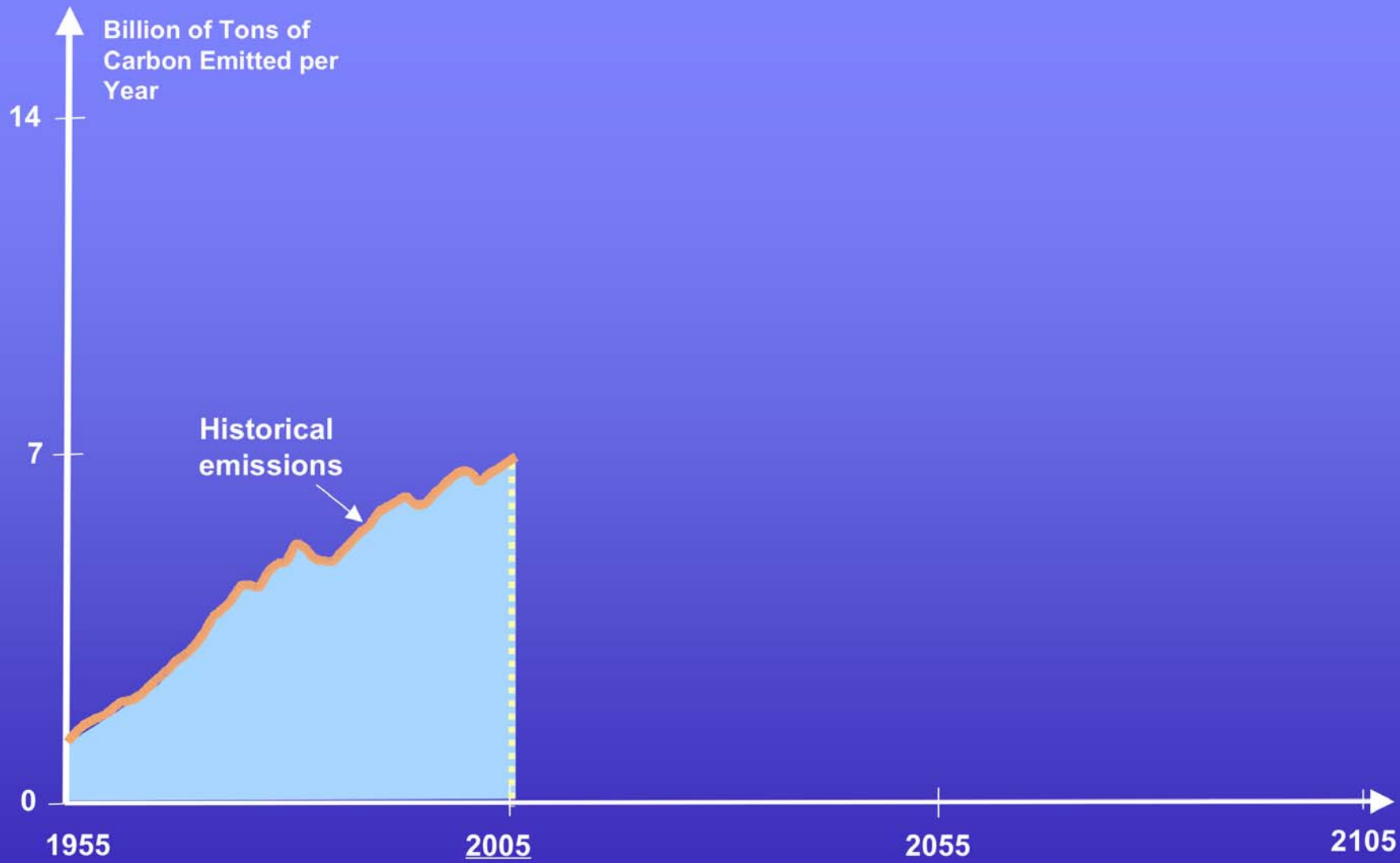
A Plethora of Scenarios



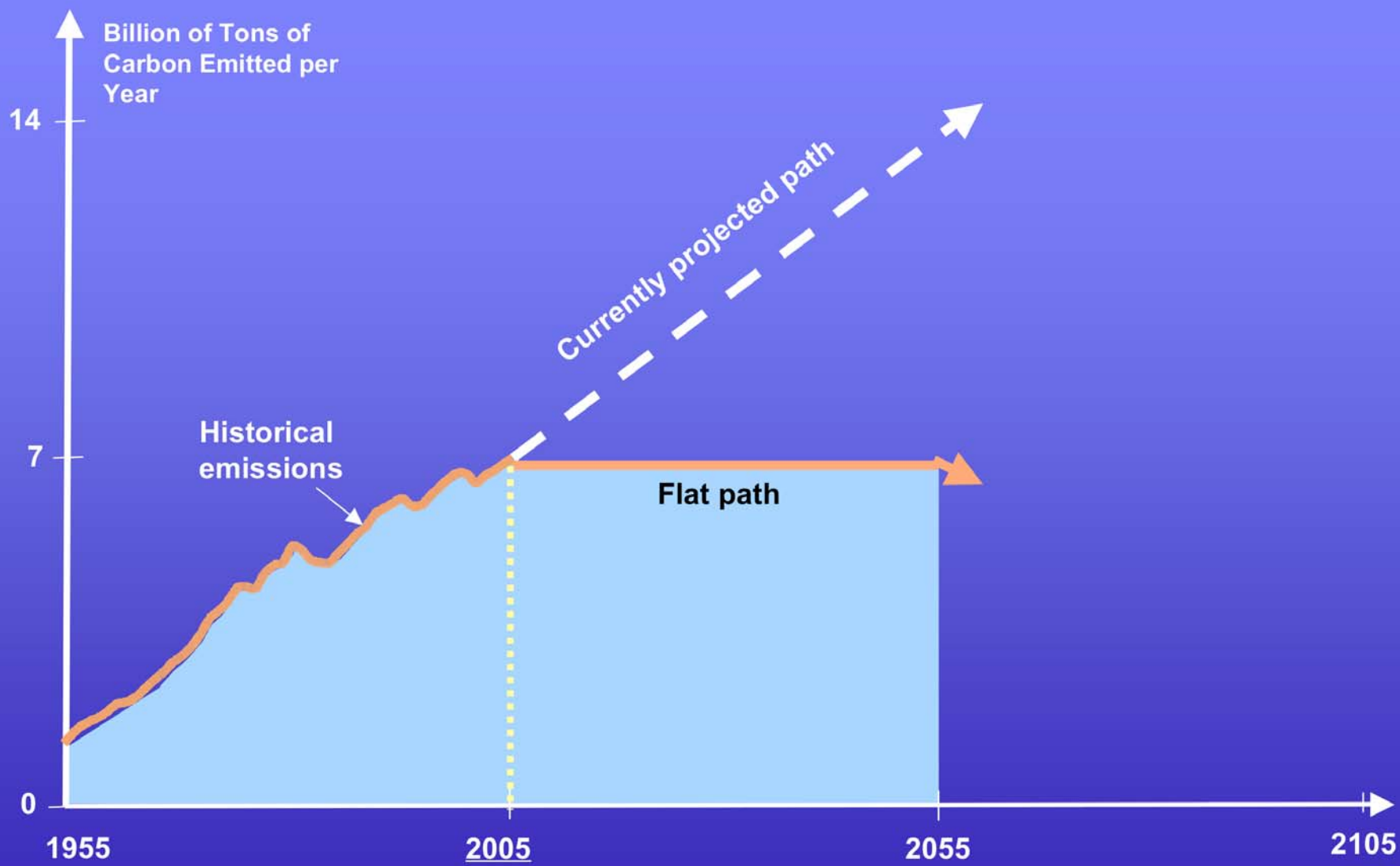
Graphic courtesy of IPCC

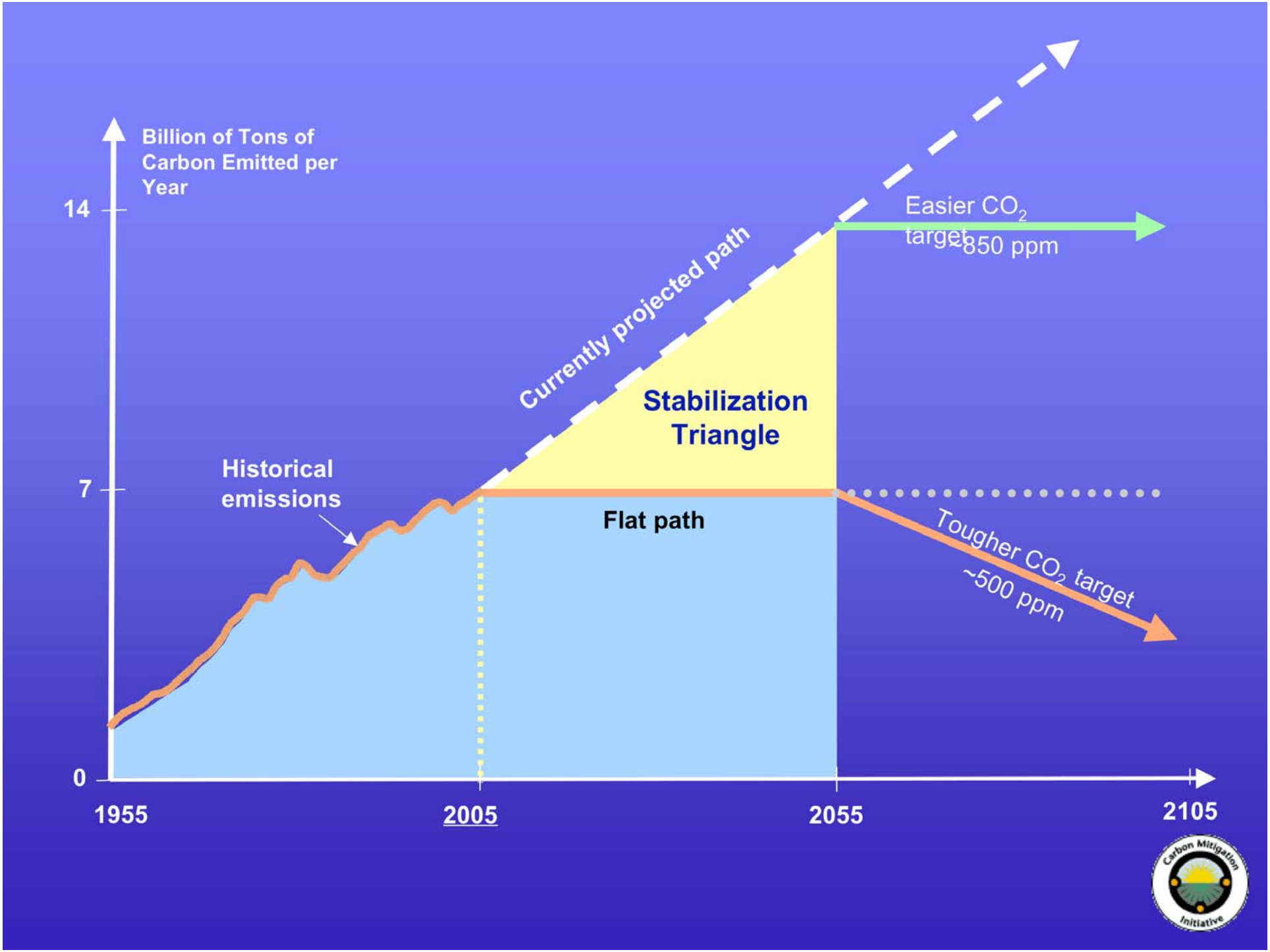
Predicted global temperature change of 1.4 - 5.8°C by 2100

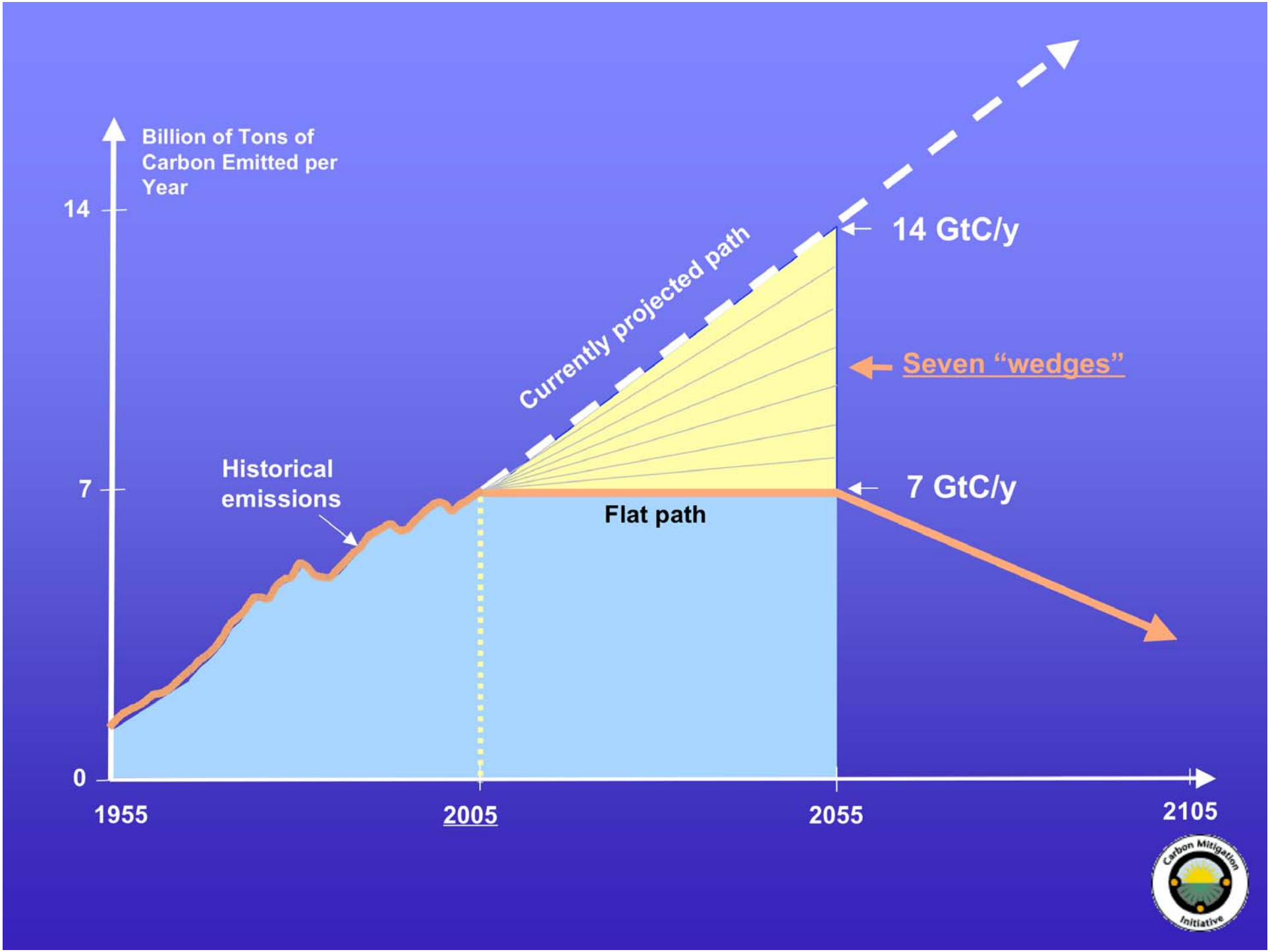
The Stabilization Wedge – Two Scenarios



The Stabilization Wedge – Two Scenarios




Billion of Tons of Carbon Emitted per Year
14
7
0
1955
2005
2055
2105
Historical emissions
Currently projected path
Stabilization Triangle
Flat path
Easier CO_2 target ~850 ppm
Tougher CO_2 target ~500 ppm
Carbon Mitigation Initiative


Billion of Tons of Carbon Emitted per Year
14
7
0
Historical emissions
Currently projected path
14 GtC/y
Seven "wedges"
7 GtC/y
Flat path
1955
2005
2055
2105
Carbon Mitigation Initiative

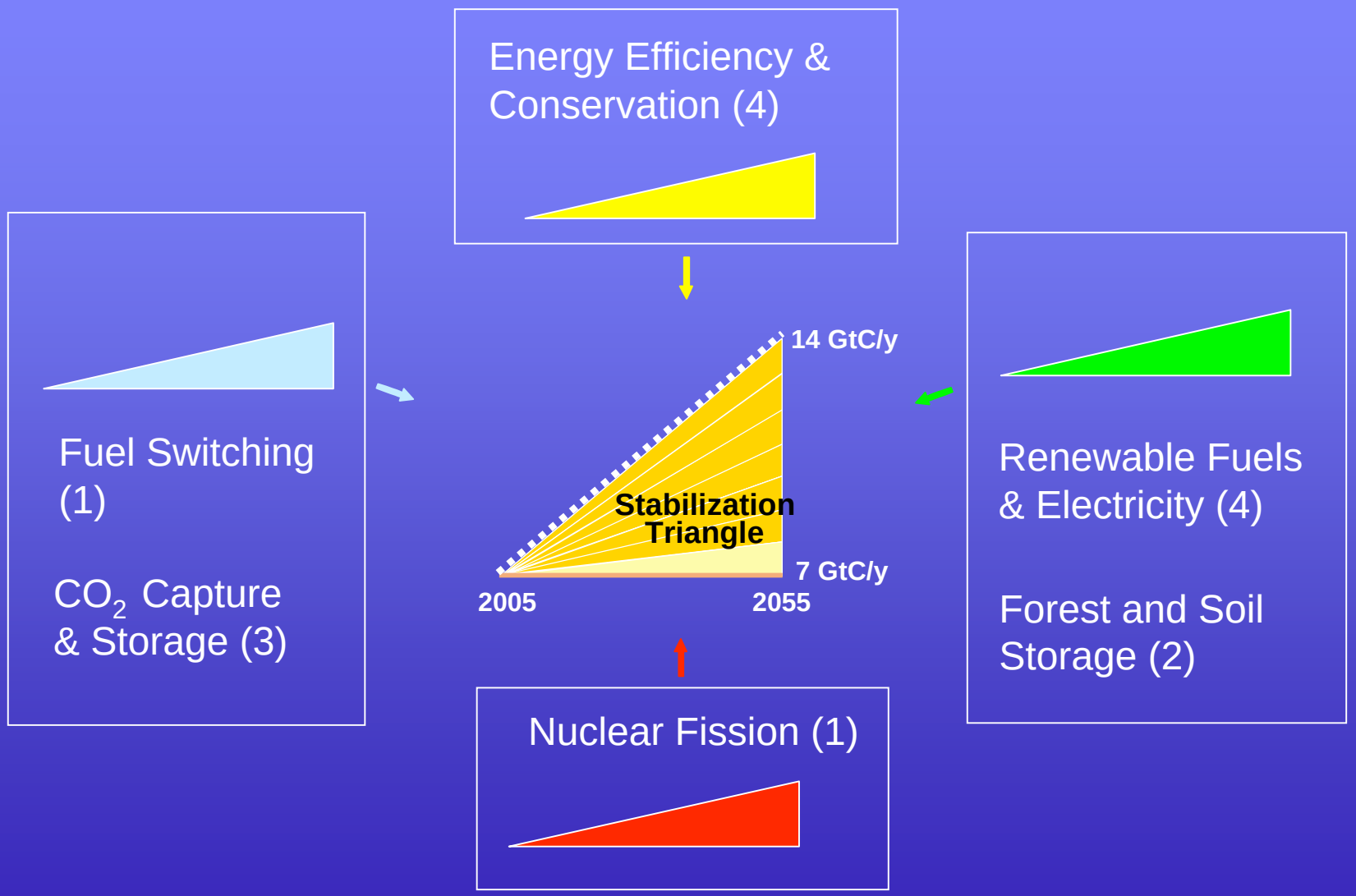
What is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.

Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

A "solution" to the CO_2 problem should provide at least one wedge.

15 Wedge Strategies in 4 Categories



Photos courtesy of Ford Motor Co., DOE, EPA

Efficiency

Double the fuel efficiency of the world's cars or halve miles traveled

There are about 600 million cars today, with 2 billion projected for 2055

Produce today's electric capacity with double today's efficiency

Average coal plant efficiency is 32% today

Use best efficiency practices in all residential and commercial buildings

Replacing all the world's incandescent bulbs with CFL's would provide 1/4 of one wedge

E, T, H / $

Sector s affected:

E = Electricity, T =Transport, H = Heat

Cost based on scale of $ to $$$

Fuel Switching

Photo by J.C. Willett (U.S. Geological Survey).

Substitute 1400 natural gas electric plants for an equal number of coal-fired facilities

A wedge requires an amount of natural gas equal to that used for all purposes today

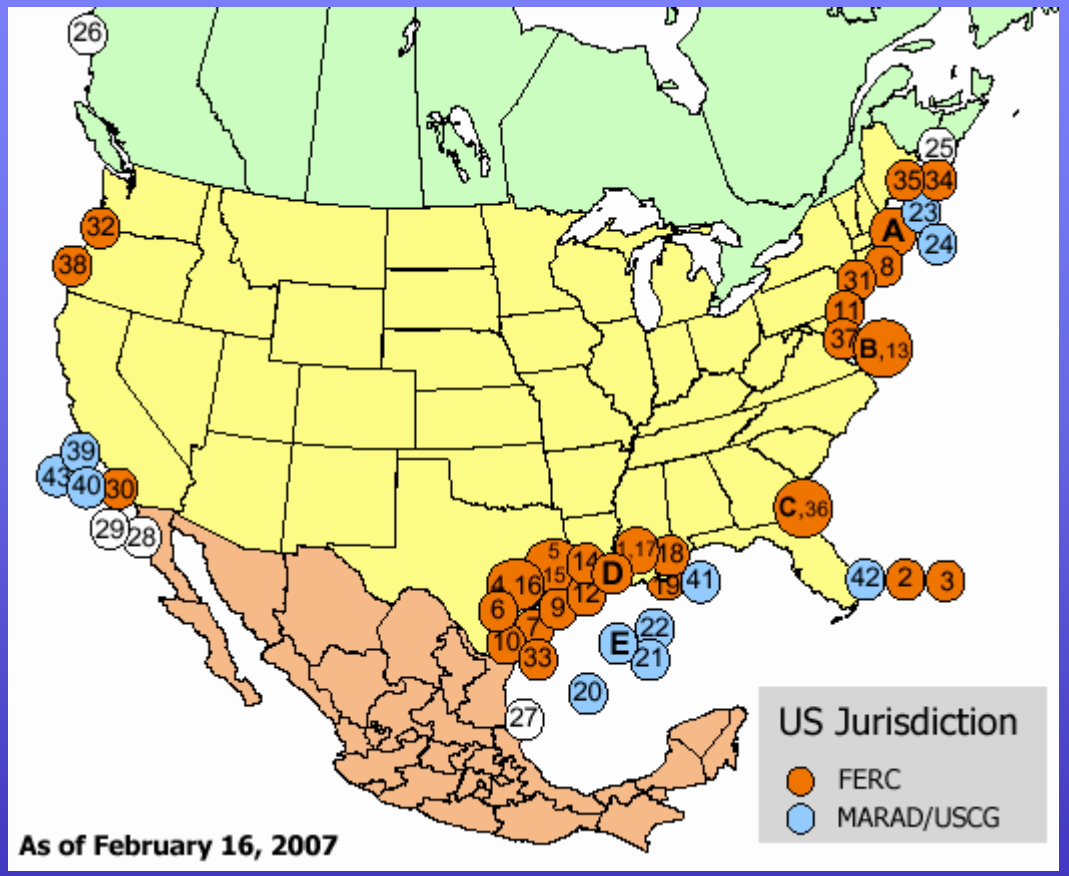
A wedge worth of natural gas requires about 190 bscfd - U.S. currently imports about 17 bscfd

E, H / $

Existing Eastern LNG Terminals

FERC

Existing and Proposed North American LNG Terminals

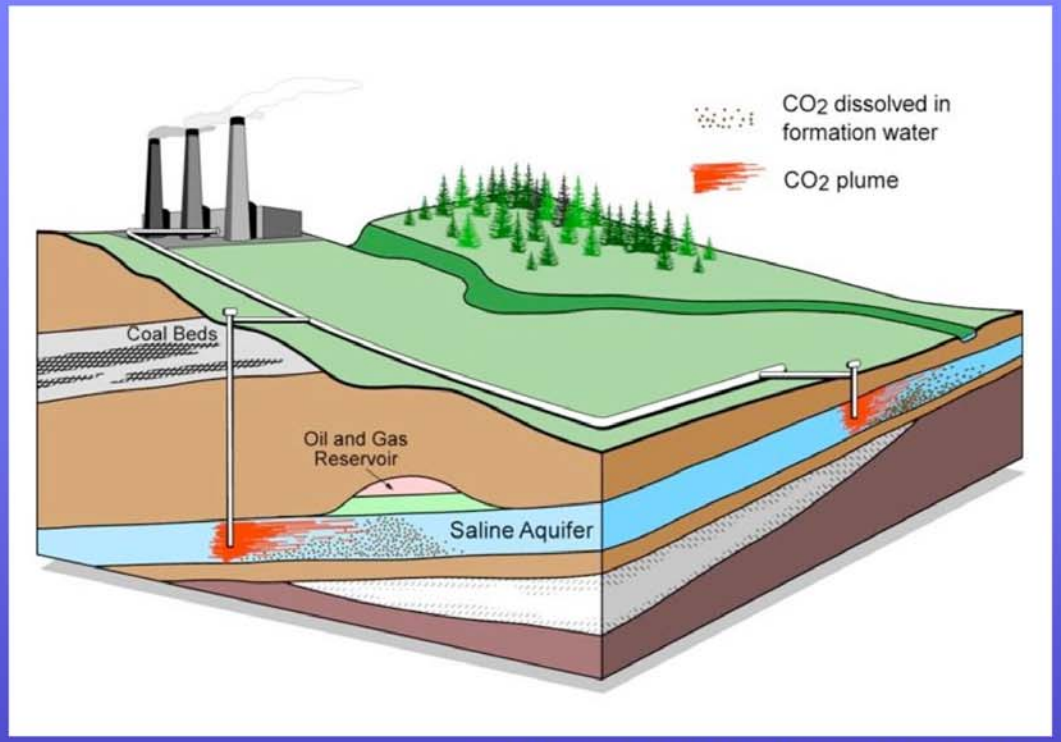


FERC

Carbon Capture & Storage

Implement CCS at

- **800 GW coal electric plants or**
- **1600 GW natural gas electric plants or**
- **180 coal synfuels plants or**
- **10 times today's capacity of hydrogen plants**

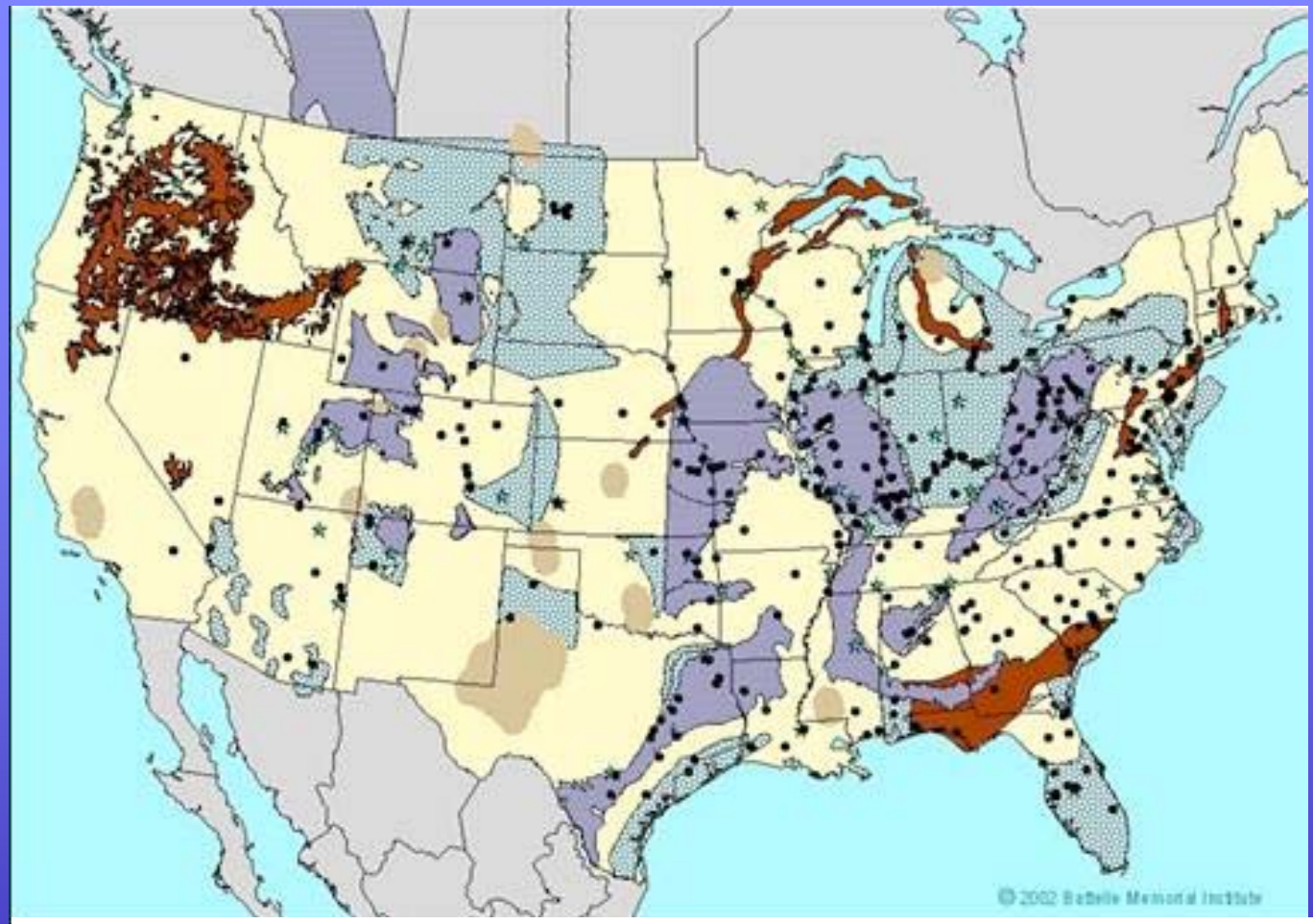


Graphic courtesy of Alberta Geological Survey

There are currently three storage projects that each inject 1 million tons of CO_2 per year – by 2055 need 3500.

E, T, H / $$

Requires about 100 times the amount of CO_2 currently injected annually for EOR (most in the U.S.)



Legend: **Red=Basalt formations, Beige=Enhanced oil recovery sites, Purple=Unmineable coal seams, Blue=Brine formations.**

JJ Dooley. "Clean, Affordable, Secure Energy for a Carbon-Constrained World." Strategic Initiatives for Coal and Power, US Department of Energy, Office of Fossil Energy. Wye Plantation, MD. PNNL-SA-37737. December 2002. Note: This map provides a preliminary illustration, pending compilation of data to be gathered as part of MRCSP activities. The Region has numerous potential geologic storage reservoirs, which, in many places, lie on top of one another; however, the stacking of reservoirs is not apparent in this two-dimensional map.

Nuclear Electricity

Triple the world's nuclear electricity capacity by 2055

Graphic courtesy of NRC

The rate of installation required for a wedge from electricity is equal to the global rate of nuclear expansion from 1975-1990.

E/ $$

104 of world's 435 nuclear electric plants are in the United States

Wind Electricity

Photo courtesy of DOE

Install 1 million 2 MW windmills to replace coal-based electricity,

OR

Use 2 million windmills to produce hydrogen fuel

A wedge worth of wind electricity will require increasing current capacity by a factor of 40

Current U.S. capacity about 11,000 MW

E, T, H / $-$$

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Solar Electricity

Photos courtesy of DOE Photovoltaics Program

Install 20,000 square kilometers for dedicated use by 2054

A wedge of solar electricity would mean increasing current capacity 700 times

E / $$$

US PV potential estimated to be ~500 GW

(Navigant Consulting and Clean Power Research, Study for the Energy Foundation)

Carbon Mitigation Initiative

Biofuels

Scale up current global ethanol production by 30 times

Photo courtesy of NREL

Using current practices, one wedge requires planting an area the size of India with biofuels crops

Need ~1000 billion barrels ethanol per year for a wedge – U.S. currently producing ~22 billion barrels/yr

T, H / $$

Natural Sinks

Eliminate tropical deforestation

OR

Plant new forests over an area the size of the continental U.S.

OR

Use conservation tillage on *all* cropland (1600 Mha)

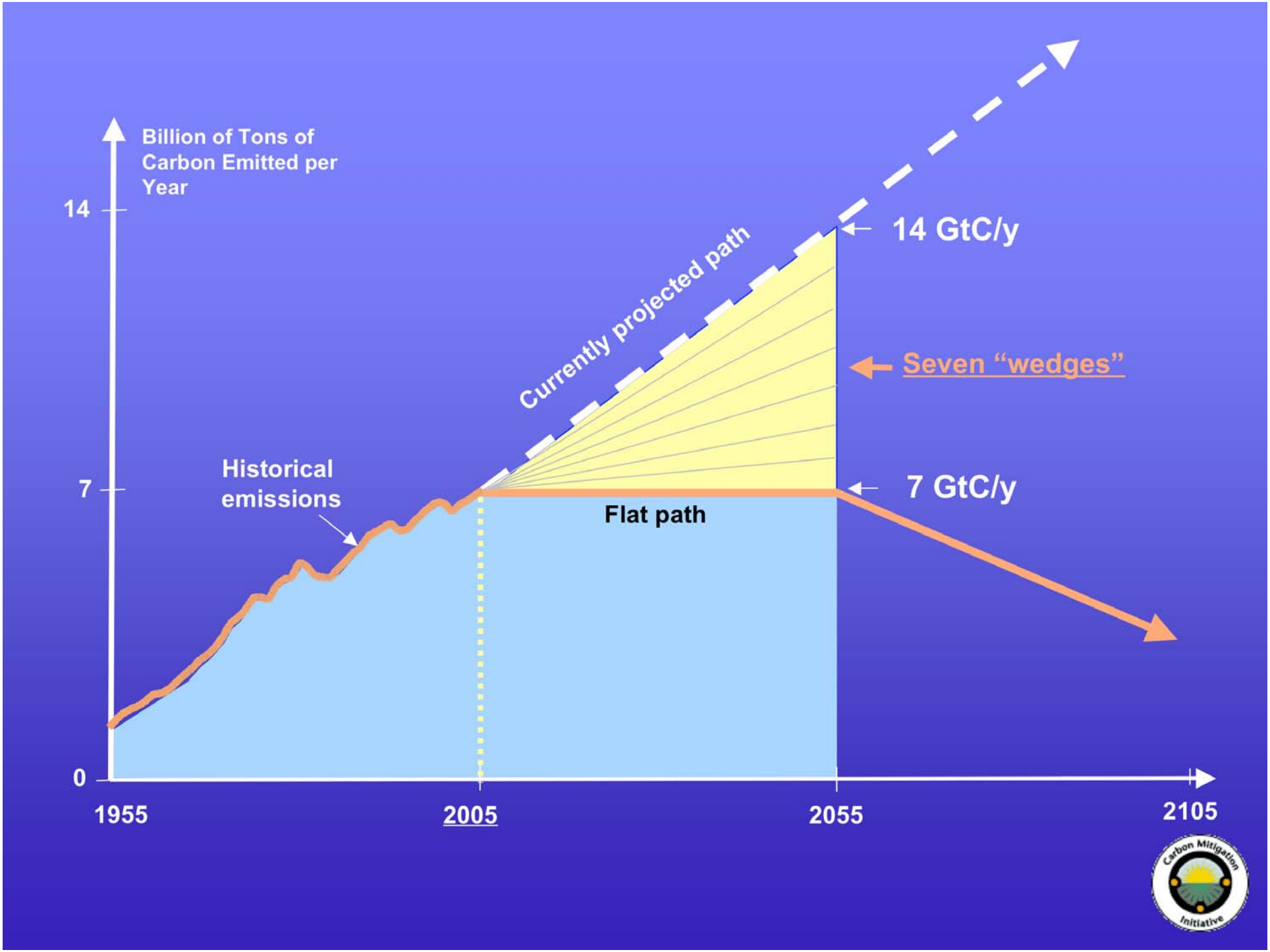
Conservation tillage is currently practiced on less than 10% of global cropland

U.S. forest sequestration potential estimated at 100-200 million tons C/yr

(Birdsey et al.)

B / $

Photo courtesy of NREL, SUNY Stonybrook, United Na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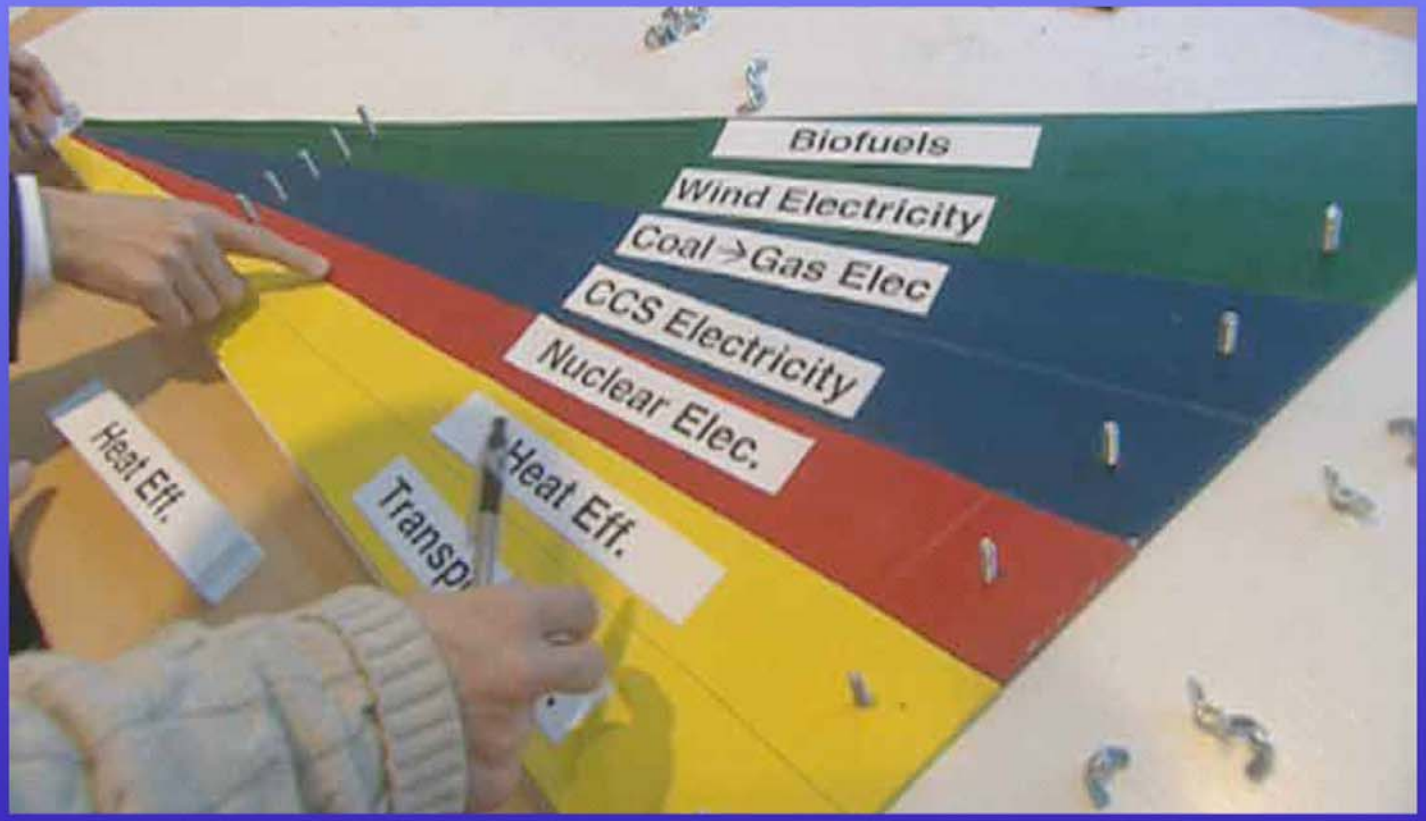
Carbon Mitigation Initiative

Take Home Messages

- In order to avoid a doubling of atmospheric CO_2, we need to rapidly deploy low-carbon energy technologies and/or enhance natural sinks
- We already have an adequate portfolio of technologies to make large cuts in emissions
- No one technology can do the whole job – a variety of strategies will need to be used to stay on a path that avoids a CO_2 doubling
- Every "wedge" has associated impacts and costs

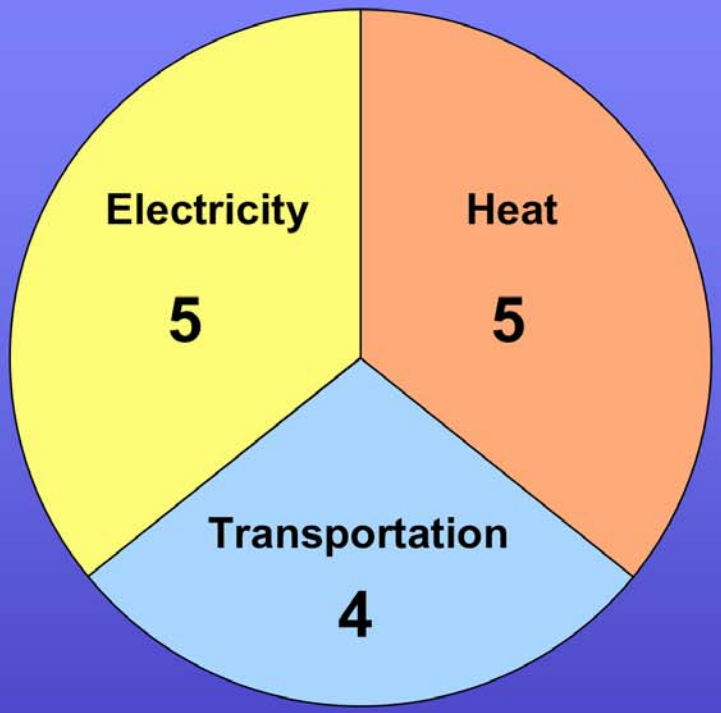
Playing the Wedges Game



Carbon Emissions by Energy Sector

Need 7 wedges...

... not all cuts can come from one sector!



"Biostorage" wedges do not count against an energy sector

Use the Wedges Table to compare Wedge Strategies

= Electricity Production, =Heating and Direct Fuel Use, =Transportation, = Biostorage

Strategy	Sector	Description	1 wedge could come from…	Cost	Challenges
1. Efficiency – Transport		Increase automobile fuel efficiency (2 billion cars projected in 2050)	**… doubling the efficiency of the all world's cars from 30 to 60 mpg**	**$**	Car size & power
2. Conservation - Transport		Reduce miles traveled by passenger and/or freight vehicles	**… cutting miles traveled by all passenger vehicles in half**	**$**	Increased public transport, urban design
3. Efficiency - Buildings		Increase insulation, furnace and lighting efficiency	**… using best available technology in all new and existing buildings**	**$**	House size, consumer demand for appliances
4. Efficiency – Electricity		Increase efficiency of power generation	**… raising plant efficiency from 40% to 60%**	**$**	Increased plant costs
5. CCS Electricity		CO_2 from fossil fuel power plants captured, then stored underground (700 large coal plants or 1400 natural gas plants)	**… injecting a volume of CO_2 every year equal to the volume of oil extracted**	**$$**	Possibility of CO_2 leakage
6. CCS Hydrogen		Hydrogen fuel from fossil sources with CCS displaces hydrocarbon fuels	**… producing hydrogen at 10 times the current rate**	**$$$**	New infrastructure needed, hydrogen safety issues
7. CCS Synfuels		Capture and store CO_2 emitted during synfuels production from coal	**… using CCS at 180 large synfuels plants**	**$$**	Emissions still only break even with gasoline
8. Fuel Switching – Electricity		Replacing coal-burning electric plants with natural gas plants (1400 1 GW coal plants)	**… using an amount of natural gas equal to that used for all purposes today**	**$**	Natural gas availability
9. Nuclear Electricity		Displace coal-burning electric plants with nuclear plants (2 x current capacity)	**… ~3 times the effort France put into expanding nuclear power in the 1980's, sustained for 50 years**	**$$**	Weapons proliferation, nuclear waste, local opposition
10. Wind Electricity		Wind displaces coal-based electricity (30 x current capacity)	**… using area equal to ~3% of U.S. land area for wind farms**	**$$**	Not In My Back Yard (NIMBY)

What are we going to do?

- Break into teams
- Choose 7 strategies to fill your stabilization triangle (30 minutes)
  - You can use each strategy more than once
  - Consider impacts and costs of each strategy
- Present your results to the group

Which wedge strategy should be added to the portfolio next?

EFFICIENCY AND CONSERVATION

- **Transport Efficiency**
- **Reduced Mileage**
- **Building Efficiency**
- **Efficient Electricity Production**

FOSSIL-FUEL-BASED STRATEGIES

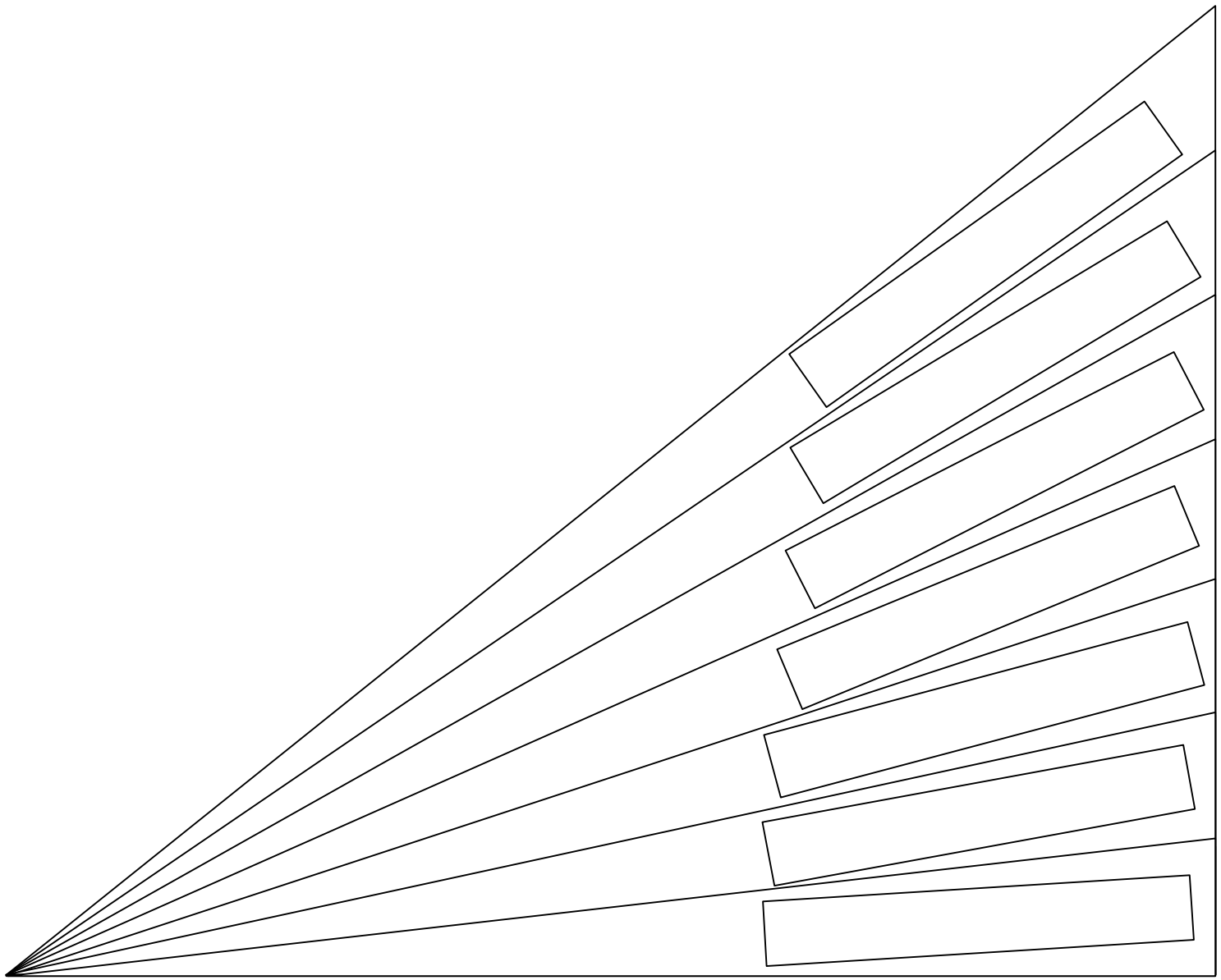
5. **CO_2 Capture and Storage (CCS) with Electricity**
6. **CCS with Hydrogen Production from Coal**
7. **CCS with Synthetic Fuels (Synfuels) from Coal**
8. **Fuel Switching (Natural Gas instead of Coal) for Electricity**

NUCLEAR ENERGY

9. **Nuclear Electricity**

RENEWABLES AND BIOSTORAGE

10. **Wind Electricity**
11. **Solar Electricity**
12. **Wind Hydrogen**
13. **Biofuels**
14. **Forest Storage**
15. **Soil Storage**



Advantages of the Wedges

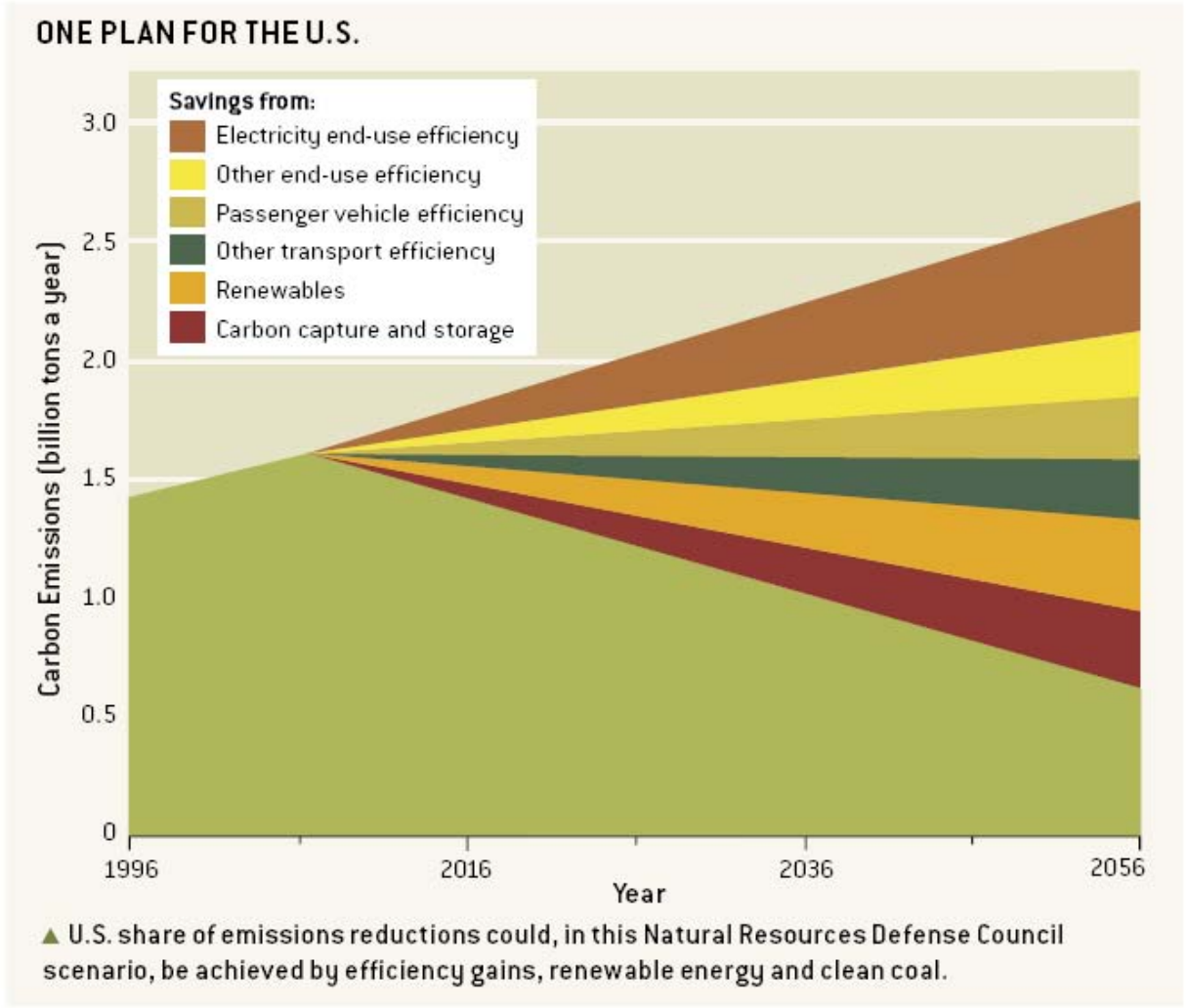
- Relatively fun way to convey issues of scale to people with broad range of experience in climate change
- Allows participants with limited expertise to knowledge-ably compare and contrast the impacts of various carbon mitigation strategies
- Fosters good discussion among people from different backgrounds by forcing participants to make tough choices
- Provides interesting non-threatening interaction on a “hot-button” issue (& potentially lots of data)

Comparison Among 3 Games

	Princeton	WRI	Melbourne
CCS (E)	X	X	
Coal to gas (E)		X*	X
Coal to gas (H)	X		
Efficiency (E)	X	X	X
Efficiency (T)	X	X	X
Efficiency (H)	X	X	X
Nuclear (E)			X
Biofuels	X	X	
Wind (E)	X	X	
Natural Sinks		X*	X
Solar (E)			X
CCS H2			
Wind H2			
Nuclear H2			

X* = two-way tie

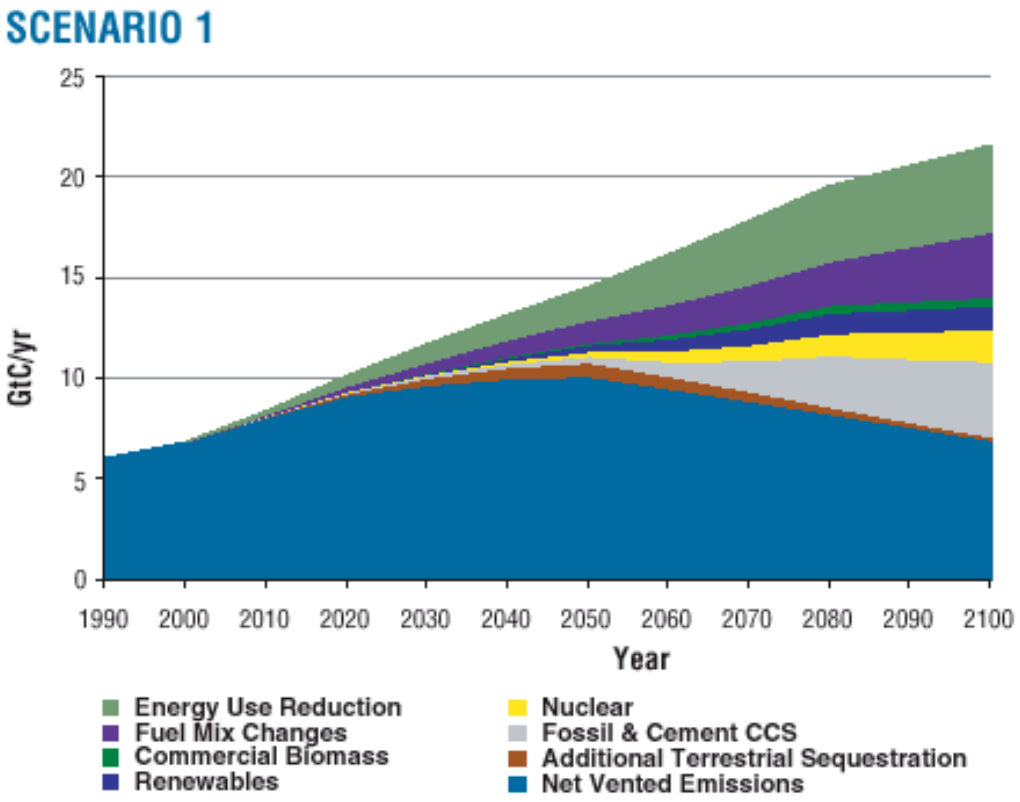
U.S. Wedges



Source: Lashof and Hawkins, NRDC, *in* Socolow and Pacala, *Scientific American*, September 2006, p. 57

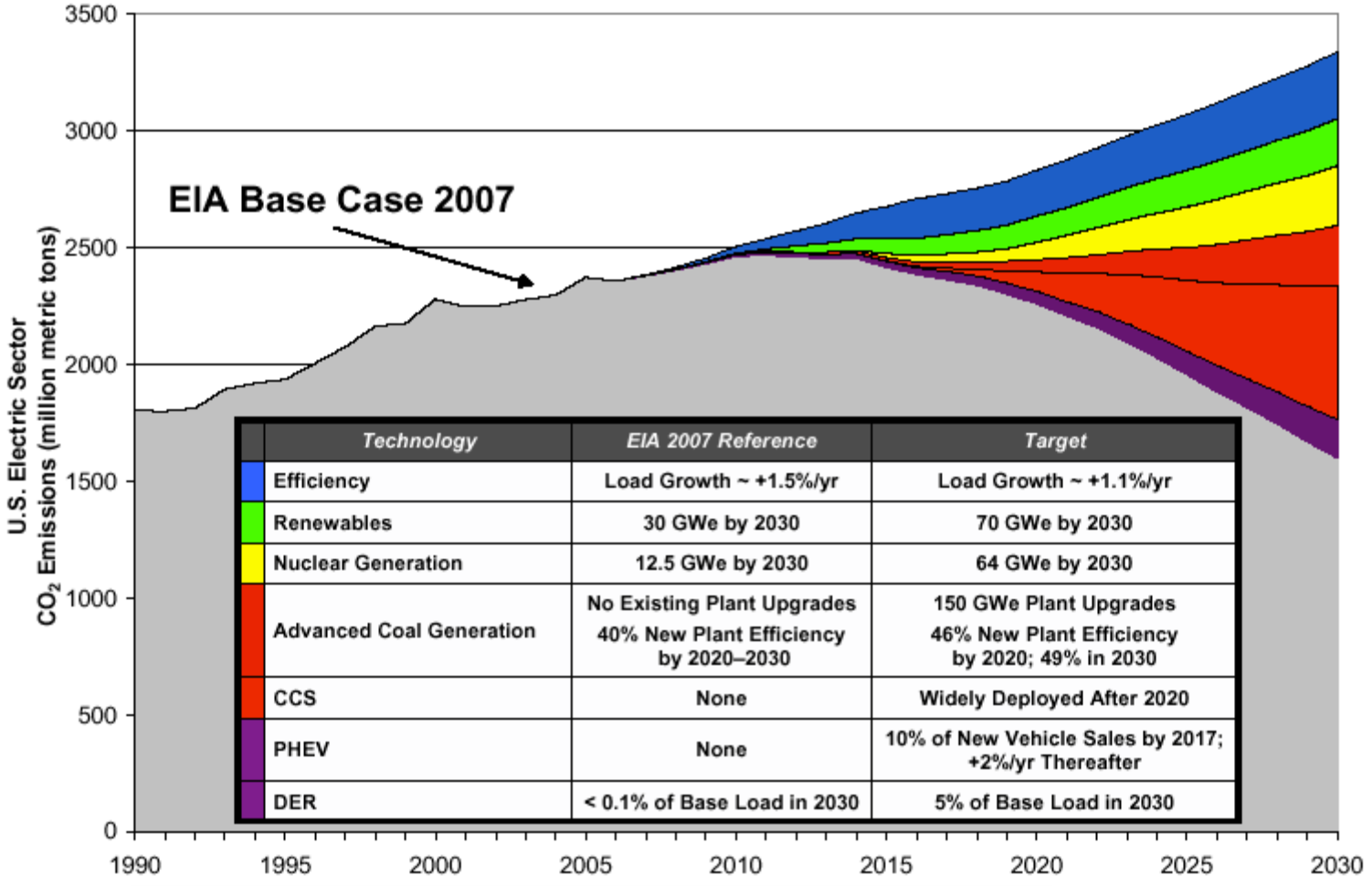
U.S. Climate Technology Program Strategic Plan

World Carbon Dioxide Emissions for Three Advanced Technology Scenarios Under a High GHG-Emissions-Constraint Case



Scenario 1 assumes successful development of carbon capture and storage technologies for use in electricity,as well as in applications such as hydrogen and cement production.

CO_2 Reductions – Technological Potential



Technology	EIA 2007 Reference	Target
Efficiency	Load Growth ~ +1.5%/yr	Load Growth ~ +1.1%/yr
Renewables	30 GWe by 2030	70 GWe by 2030
Nuclear Generation	12.5 GWe by 2030	64 GWe by 2030
Advanced Coal Generation	No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030	150 GWe Plant Upgrades 46% New Plant Efficiency by 2020; 49% in 2030
CCS	None	Widely Deployed After 2020
PHEV	None	10% of New Vehicle Sales by 2017; +2%/yr Thereafter
DER	< 0.1% of Base Load in 2030	5% of Base Load in 2030

** Achieving all targets is very aggressive, but potentially feasible.*

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Or visit our wedges webpage at
http://www.princeton.edu/wedges